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# Modelling and simulation of the Magnetically Impelled Arc Butt (MIAB) process for transmission pipeline applications

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# MODELLING AND SIMULATION OF THE MAGNETICALLY IMPELLED ARC BUTT (MIAB) PROCESS FOR TRANSMISSION PIPELINE APPLICATIONS

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## ABSTRACT

Early patents for the Magnetically Impelled Arc Butt process (MIAB) date back to 1940 [1] and the basic principles of the process have remained unchanged from this time. The process was however refined in the 1970s for use in the production of automotive components and has been used extensively in this area. Investigation of the process for pipe girth welding have been reported and commercial pipe welding heads are reported to be available in the Ukraine [2]. Although the process is well established it is believed that a more fundamental analysis of the mechanisms involved would assist in the optimisation of operating parameters. The current work is aimed at modeling the process to assist in its development for small diameter thin walled transmission and distribution pipelines. The paper describes the initial steps in this research.

## KEYWORDS

Welding, MIAB, Magnetic Fields, Simulation

## AUTHOR DETAILS

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## 1. INTRODUCTION

The Magnetically Impelled Arc Butt welding process is well established in the automotive industry for joining small tubular components [3,4], often in safety critical areas. An Australian review of process options for pipeline girth welding in 1997 [5] suggested that the feasibility of MIAB welding for girth welding of small diameter transmission pipelines should be examined. The basis for this suggestion was the fact that the one shot process allowed short joint completion times to be achieved. Various international attempts have been made to apply the process to pipeline girth welding and most recently a full scale system has been successfully demonstrated by MIAB Technology Pty in Australia.

Although the basic operating principles have been established for some time, few detailed investigations of the process mechanism and control relationships have been undertaken. The present paper describes some initial steps in a research program sponsored by the Australian Commonwealth government and MIAB Technology Pty in an attempt to elucidate the underlying mechanisms and ultimately enhance the control of the process.

### 1.1 Basic Principles

The basic principles of the process are illustrated in Figure 1. An arc is established across a small gap between the ends of the pipes to be joined. The arc is rotated rapidly around the circumference of the joint by a magnetic field of specific geometry, which is produced by controlled current flowing through the two electromagnet coils. The arc induces heating of the pipe ends and when the required temperature is reached the joint is closed by a longitudinal forging action.

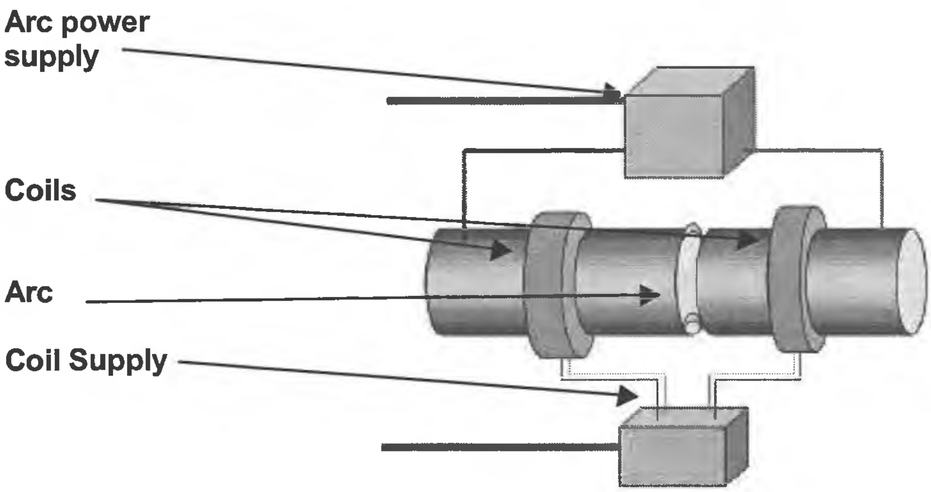


Figure 1. Schematic Representation of the MIAB System

## 2. PROCESS FEATURES

For relatively small pipe diameters (around 150 mm nominal bore) the heating cycle is typically around 10 to 12 seconds. During this cycle the arc accelerates during each revolution and progressively moves from the inside to the outside circumference of the pipe. The forging cycle is completed within 2 to 3 seconds and the finished weld is sound with a rounded flash profile on either face. Figure 2 shows a macro section of a finished weld which has been subjected to a bend test.

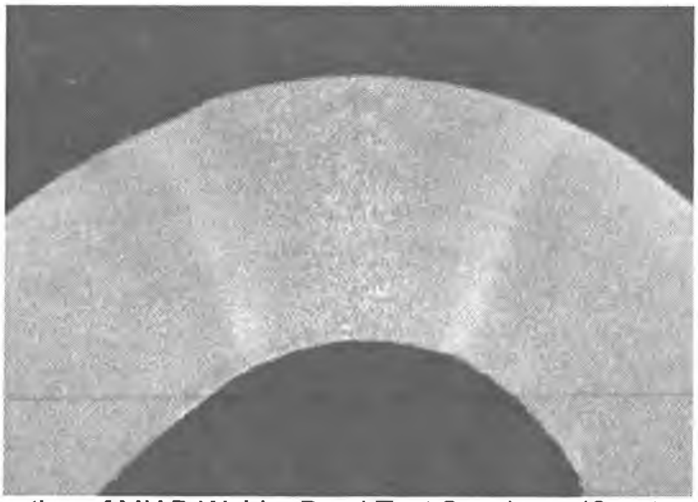

Figure 2. Macro Section of MIAB Weld – Bend Test Specimen (Courtesy of MIAB Technology Pty)

Most of the literature claims an upper thickness limit of 9 mm and indicates that uniformity of surface heating limits the application of the process to thicker walls although some researchers claim to have extended the thickness range to 19 mm.

## 3. CONTROL PARAMETERS

The main control parameters are:

- Arcing current
- Magnetic field strength
- Heating cycle time

In addition the geometry of the magnetic field, the initial arc gap and forging velocity must be considered.

## 4. PROCESS REQUIREMENTS

To form a sound joint the surfaces to be forged must be heated to a uniform high temperature to reduce its local yield strength. The decreased yield strength allows the abutting surfaces to deform during the forging stage. Contaminants are extruded from the joint, aided by superficial melting of the surfaces by the rotating arc. The extrusion allows virgin metal to establish a metallic bond across the interface. The forging force must be sufficient to achieve the surface deformation and the forging time must be limited to offset the effects of cooling when the arc is extinguished.

## 5. MAGNETIC FIELD AND ARC INTERACTION

The movement of a current-carrying conductor in a magnetic field is a well established electrical phenomenon. The direction of rotation is defined by Fleming's left hand rule as shown in Figure 3.

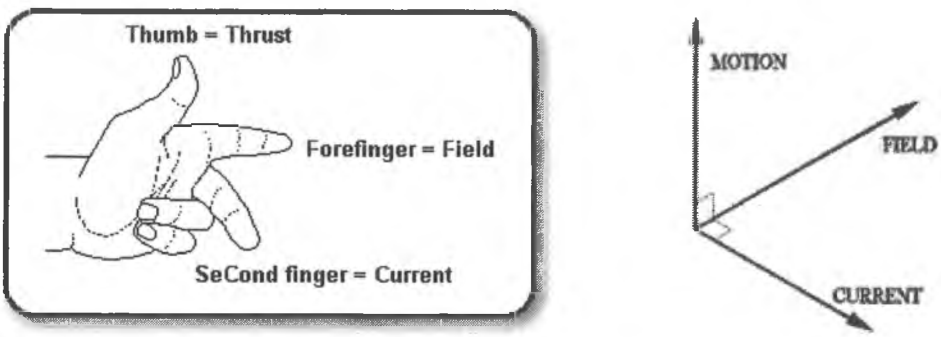


Figure 3. Fleming's Left Hand Rule

Based on this rule, it is clear that to obtain arc rotation in the MIAB process a radial magnetic field is required.

Increasing the arcing current will increase the local field strength around the arc and also increase the heating effect.

Increasing either the magnetic field strength or the arcing current should increase the rotational force on the arc and the steady-state rotation speed. There are however limits to the field strength in the air gap between the pipes, since the steel within the magnetic circuit will saturate at a finite value of coil current. In most cases, the initial saturation does not occur at the ends of the pipe, but elsewhere in the magnetic circuit.

Some of these effects have been investigated by simulation and experimental validation.

## 6. SIMULATION

The Maxwell™ magnetic simulation software was used to simulate the effect of various configurations of the system and the effects of the key magnetic control parameters.

The basic mechanical arrangement of the MIAB process to be investigated is modelled in Figure 4.

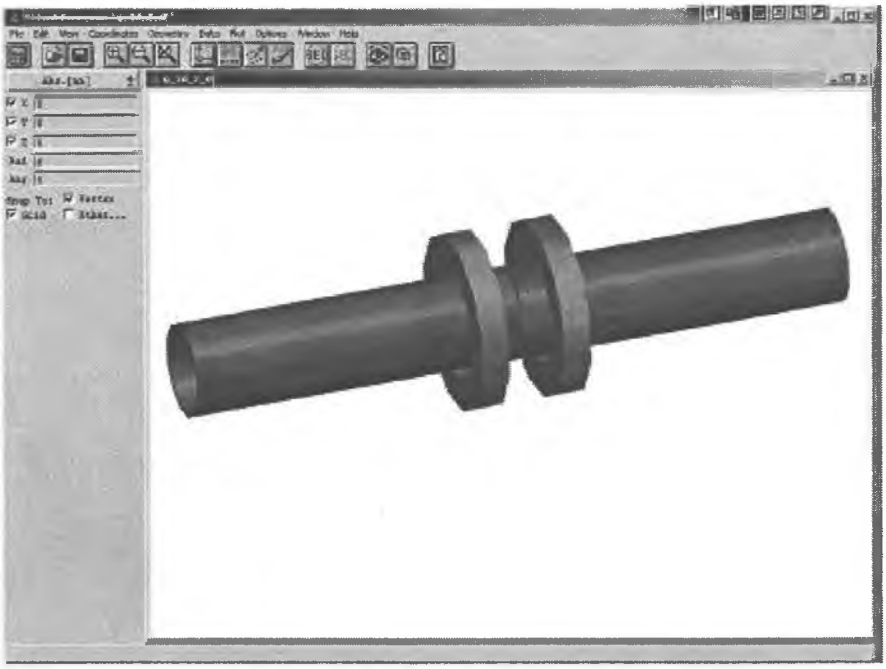

Figure 4. Overview of Simulation Model (150nb Pipes)

The solid model representation may be derived from a CAD drawing package or created within the simulation software. Various field configurations and field strengths may be applied and the physical characteristics of the pipe materials and surrounding environment may be modified. Both 2D and 3D simulations can then be carried out to calculate the magnetic field's shape, direction and strength. Figure 5 shows a 3 dimensional simulation of the magnetic flux density at the surface of the pipe sections. Figure 6 shows a 2D plot of the total magnetic field surrounding the pipes. Figure 7 is a 3D plot indicating the direction and intensity of the magnetic field in the vicinity of the air gap between the pipe ends.

Simulations such as these are being used to select appropriate parameters and to design magnetic path configurations which will ensure uniform arc heating of the joint prior to forging.

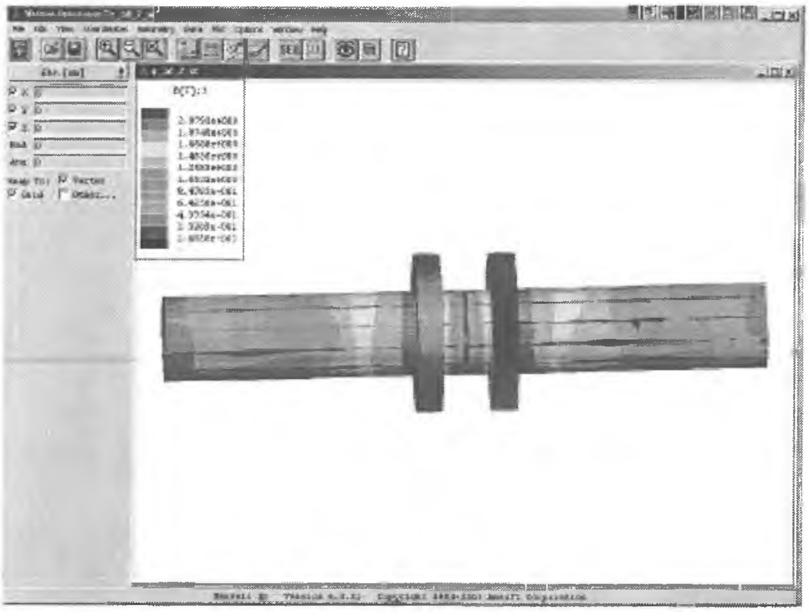

Figure 5. Magnetic Flux Density in the Pipe Sections

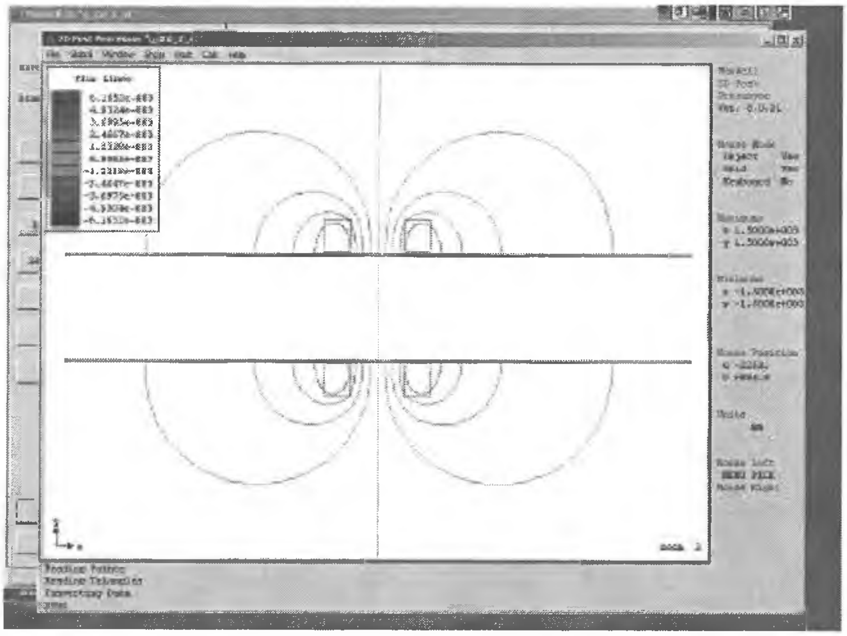

Figure 6. Equipotential Lines of Magnetic Flux

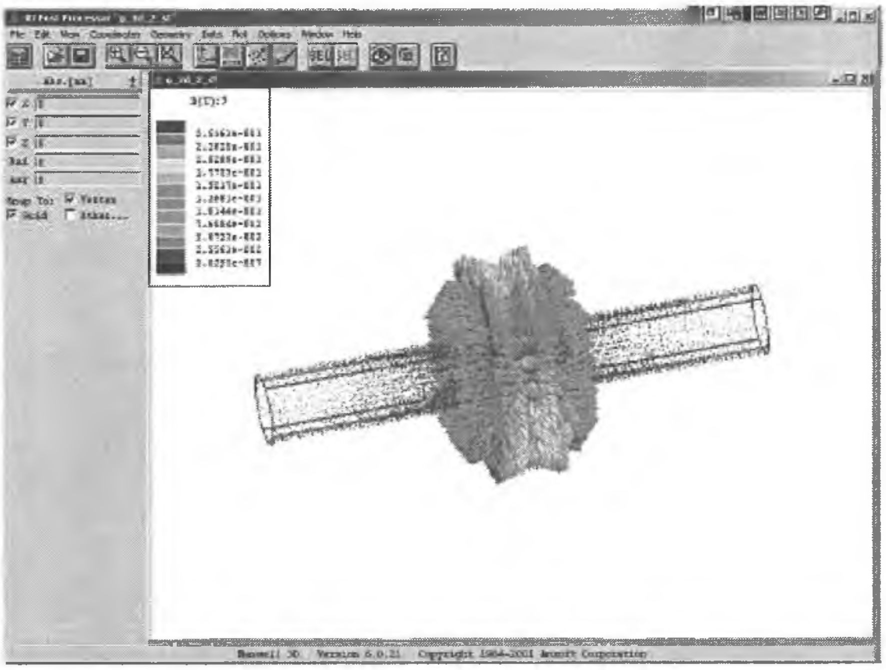

Figure 7. 3D Plot of Magnetic Flux Around the Pipe

## 7. EXPERIMENTAL INVESTIGATION

In order to investigate arc performance, the effect of the welding control parameters, and to validate the simulations above, an experimental MIAB test rig has been constructed at UOW.

The welding head is shown in Figure 8. The design allows for support and alignment of two 600 mm lengths of 150 mm nominal bore pipe. Two electromagnetic coils can be located at any position along the length of the pipes. These coils are powered from individual power supplies. A power source with 1000 Amp current capability is used to supply the arcing current.

The system currently has no forging capability, since the main research focus is on arc diagnostics and pre-forge heating effects. Video filming, thermal measurements and voltage probe techniques will be used to monitor the arc behaviour on an instantaneous basis.

The cell has recently been commissioned and trials have commenced.

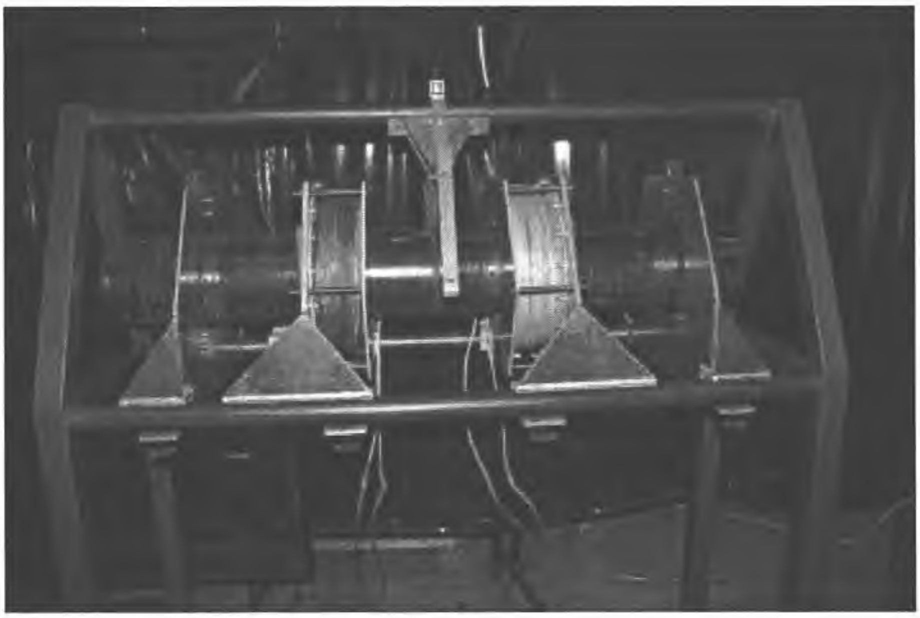

Figure 8. Experimental Test Rig for MIAB Arc Studies

## 8. SUMMARY

The MIAB welding process is an attractive alternative to manual metal arc and gas metal arc techniques for girth welding of pipe. In order to optimise the process, a better understanding of the process physics is likely to be needed. Using finite element simulation and basic experimental studies it is hoped to elucidate the controlling mechanisms in order to determine suitable operating parameters and magnetic field geometries for typical transmission pipeline applications.

## 9. ACKNOWLEDGEMENTS

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